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Cosmological Constants as Messenger between Branes

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Abstract

We present a supersymmetry-breaking scenario in which both the breaking in the hidden sector with no-scale type supergravity and that in the observable sector with gauge mediation are taken into account. The breaking scales in the hidden and observable sectors are related through the vanishing condition of the cosmological constant with a brane-world picture in mind. Suppressing flavor-changing neutral currents, we can naturally obtain the gravitino, Higgs(ino), and soft masses of the electroweak scale.

In supergravity, supersymmetry(SUSY)-breaking effects in a (so-called) hidden sector are transmitted into the observable sector through nonrenormalizable interactions [1]. With a generic Kähler potential, we have arbitrary soft SUSY-breaking masses for squarks and sleptons, which generate too large flavor-changing neutral currents(FCNC's) at low energies [2]. A solution to this problem is to consider that the hidden sector responsible for the SUSY breaking is fully separated from the observable sector not only in the superpotential W but also in the Kähler potential K. However, physical contents of the separation of two sectors depend strongly on the frames we take in supergravity.

The most popular separation is given in the Einstein frame [1], which generates a common SUSY-breaking mass for all squarks and sleptons. This degeneracy in the soft masses suppresses sufficiently the unwanted FCNC's [2]. Although the separation in the Einstein frame is well consistent with experimental constraints, the origin of the separation is not clear enough.

An alternative has been proposed in Ref. [3] which assumes the separation in the "conformal" frame in supergravity. The Kähler potential $\mathcal{K}$ and superpotential W are postulated to have the following forms [3]:

$$\mathcal{L} = \int d^2\Theta\, 2\mathcal{E} \left[-\frac{1}{8}(\bar{\mathcal{D}}\bar{\mathcal{D}} - 8R)\, \mathcal{K}(Q, Q^\dagger, Z, Z^\dagger) + W(Q, Z) \right] + \text{h.c.}; \tag{1}$$

$$\mathcal{K}(Q, Q^\dagger, Z, Z^\dagger) = -3 + f_O(Q, Q^\dagger) + f_H(Z, Z^\dagger), \tag{2}$$

$$W(Q, Z) = W_O(Q) + W_H(Z). \tag{3}$$

Here, Q and Z denote fields in the observable and hidden sectors, respectively. In the Einstein frame, we see that the Kähler potential K has the form of no-scale type[1] as

$$K(Q, Q^\dagger, Z, Z^\dagger) = -3 \log \left(1 - \frac{1}{3} f_O(Q, Q^\dagger) - \frac{1}{3} f_H(Z, Z^\dagger) \right). \tag{4}$$

It is interesting that the above separation of the hidden and observable sectors is stable against radiative corrections due to matter-field loops, and we may expect some underlying

[1]The no-scale supergravity [4] adopts a specific form $f_H = Z + Z^\dagger$.

physics that naturally explains the separation. Recently, Randall and Sundrum [5] have suggested a beautiful geometric explanation on the hidden and observable separation in the "conformal" frame. They have claimed that the hidden and observable sectors live on different three-dimensional "branes" separated by a gravitational bulk [6] in higher-dimensional spacetime. Although the details of the seraration are not fully clarified, the picture of geometric separation may deserve further investigation.

It is a crucial observation in Ref. [3] that all soft SUSY-breaking masses and A terms in the observable sector vanish in the limit of the zero cosmological constant. All gaugino masses in the observable sector also vanish because of the decoupling of hidden field Z from the gauge kinetic function [5]. The B term of Higgs fields is exclusively the soft SUSY-breaking parameter in the observable sector, which arises from the F component of an auxiliary field Φ of the gravitational supermultiplet [5]. The soft SUSY-breaking mass B should be chosen as $B \lesssim 1$ TeV to cause naturally the electroweak symmetry breaking at $O(100)$ GeV. This requires the gravitino mass $m_{3/2} \lesssim 1$ TeV, and we take here $m_{3/2} \sim$ 1 TeV. In these circumstances, the anomaly mediation [5, 7] generates too small SUSY-breaking masses in the observable sector and hence the gauginos, squarks, and sleptons remain almost massless, rendering the proposals in Ref. [3, 5] unsatisfactory.

The above argument leads us to consider another source of SUSY breaking in the observable sector and postulate gauge mediation [8] yielding sufficiently large SUSY-breaking masses for the SUSY standard-model particles.[2] However, this scenario has a manifest drawback: there is no reason why the scale of SUSY-breaking masses (of order 100 GeV $-$ 1 TeV) in the observable sector coincides with the gravitino mass $m_{3/2}$ arising from the hidden sector, since the two branes corresponding to the two sectors are separated by a bulk and the dynamics on each brane are most likely independent.

In this paper, we consider a possible scenario where the dynamical scale on one brane is strongly related to the scale on the other brane in order to cancel vacuum energies produced

[2]Mixture of gravity and gauge mediations is considered in Ref. [9].

on the two branes. Namely, nonvanishing "cosmological constants" appearing on the two branes play a role of messenger between the hidden and observable sectors. This is plausible, for instance, if the vanishing cosmological constant in four dimensions is achieved for some higher-dimensional reasons [10] due to the presence of the bulk.

Let us consider a situation that the scale of the SUSY breaking arises dominantly on the hidden brane: the F component of a hidden chiral superfield Z is determined as $|\langle F_Z\rangle| \simeq m_{3/2}M_{\rm pl} \sim (10^{10.5}\ {\rm GeV})^2$ so that we get $m_{3/2} \sim 1$ TeV. We can fix the condensation of the superpotential to cancel the positive cosmological constant arising from the hidden-sector SUSY breaking:

$$|\langle F_Z\rangle|^2 - 3\frac{|\langle W\rangle|^2}{M_{\rm pl}^2} = 0. \tag{5}$$

Note that the bulk contribution to the vacuum condensation is implicit in the superpotential and determined by the higher-dimensional equations of motion [11]. Having higher-dimensional reasons for the vanishing cosmological constant in mind, we suspect that the vacuum energy does not cancel out predominantly within the hidden brane. Thus, we assume that the scale of the superpotential condensation is given mainly by the dynamics on the observable brane.[3] Then, we can determine the dynamical scale Λ in the observable sector responsible for the condensation as $\Lambda \sim (|\langle F_Z\rangle|M_{\rm pl})^{1/3} \sim (m_{3/2}M_{\rm pl}^2)^{1/3} \sim 10^{13}$ GeV.

For concreteness, we consider an observable-sector chiral superfield S carrying R-charge 2/3 whose condensation is given by $\langle S\rangle = \Lambda$. This is realized, for instance, by a dynamical condensation of the matter $Q\bar{Q}$ considered in Ref.[12, 13, 14] with S given by $Q\bar{Q}/M_{\rm pl}$. We have an R-symmetric superpotential as

$$W_O \supset fS^3, \tag{6}$$

which induces the superpotential condensation of an appropriate size.

The condensation affects various aspects of other components in the observable sector, since they are directly connected in the superpotential. We now discuss an example of

[3]This does not necessarily mean that the bulk cosmological constant is negligible.

possible effects. Let us adopt a SUSY SU(2) gauge theory with $2N_f$ doublet hyperquarks Q'^i_α ($\alpha = 1, 2$; $i = 1, \cdots, 2N_f$) for a demonstration of our point. We assume that the first four hyperquarks Q'^i_α ($i = 1, \cdots, 4$) carry vanishing R charges, while the remaining hyperquarks Q'^i_α ($i = 5, \cdots, 2N_f$) carry R-charge 2/3. Then, the latter hyperquarks Q'^i_α ($i = 5, \cdots, 2N_f$) acquire masses of the order of the R-breaking scale Λ through the following superpotential:

$$W_O \supset h_{ij} Q'^i Q'^j S. \tag{7}$$

Therefore, we have a SUSY SU(2) gauge theory with four massless hyperquarks Q'^i_α ($i = 1, \cdots, 4$) below the R-breaking scale Λ, and the gauge coupling becomes strong causing nontrivial dynamics at a lower energy scale $\Lambda' \sim (\Lambda_{N_f}^{6-N_f} \Lambda^{N_f - 2})^{1/4}$. Here, Λ_{N_f} denotes the dynamical scale determined by the SU(2) gauge coupling well above the scale Λ. This implies that Λ' is expected to be close to the R-breaking scale Λ for appropriate values of N_f [13]. This SU(2) gauge theory can be arranged to break SUSY dynamically. In fact, an introduction of six singlets S_{ij} ($= -S_{ji}$) ($i, j = 1, \cdots, 4$) which couple to $Q'^i Q'^j$ in the superpotential generates dynamical SUSY breaking [15], whose scale is given by the scale Λ' of the SU(2) theory.

Postulating suitable messenger fields [12, 13, 14, 16], the above SUSY breaking effects are transmitted into the SUSY standard-model sector. Analyses in Ref. [12, 13, 14, 16] suggest $\Lambda' \sim 10^5$ GeV $- 10^9$ GeV, which seems a quite reasonable value when one compares it with the R-breaking scale $\Lambda \sim 10^{13}$ GeV. This is analogous to the relation between the QCD and the electroweak symmetry-breaking scales.

We should note here that the present scenario solves two serious problems in the genuine gauge mediation. First of all, there is no μ problem. The μ term (SUSY-invariant mass for Higgs multiplets H and $\bar{H}$) arises naturally from the R-symmetry breaking [3, 17]. Namely, the Higgs supermultiplets H and $\bar{H}$ couple to the S field, provided they have vanishing R

charges, in the superpotential as

$$W_O \supset \frac{k}{M_{\rm pl}^2} H\bar{H}S^3, \tag{8}$$

which induces $\mu \simeq k \langle S \rangle^3 / M_{\rm pl}^2 \simeq 100$ GeV $- 1$ TeV. Second, the gravitino problem is less severe, since $m_{3/2} \sim 1$ TeV. The inflationary universe with reheating temperature $T_R \simeq 10^8$ GeV is consistent with the big-bang nucleosynthesis for $m_{3/2} \simeq 1$ TeV [18]. It has been shown [19], recently, that with $T_R \simeq 10^8$ GeV the leptogenesis works very well.

We have assumed, so far, the minimal SUSY standard model as for the usual quark, lepton, and Higgs fields. However, if we adopt the next-to-minimal SUSY standard model [20], the soft SUSY-breaking B term does not appear directly and hence we may raise the gravitino mass up to $m_{3/2} \sim 100$ TeV.[4] In this case, the anomaly-mediation effects [5, 7] may dominate the gaugino masses giving rise to interesting experimental signals [22], if the gaugino masses induced by the gauge mediation are suppressed as in Ref. [14]. The problem of tachyonic sleptons [5] in the anomaly mediation may be naturally solved by the gauge mediation discussed in this paper.

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